Carbon Capture and Storage Future Research Needs

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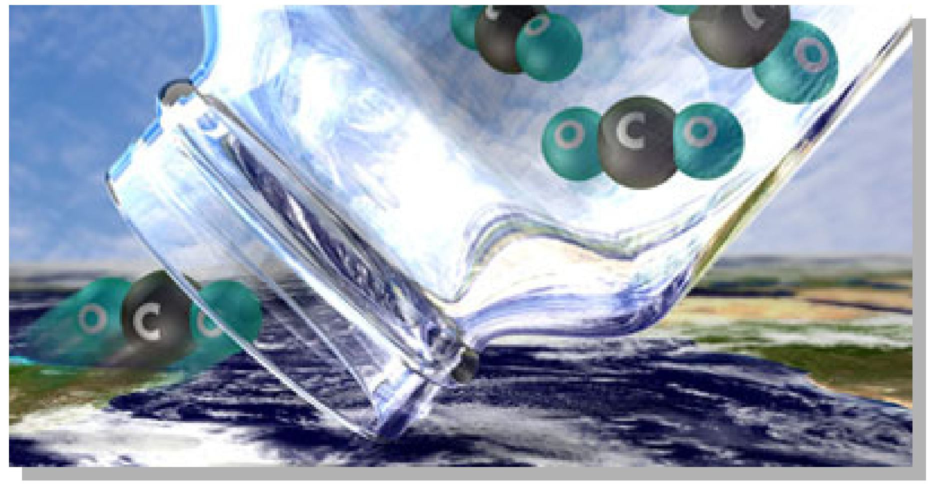
Challenges to Carbon Capture and Storage

- **Magnitude of emissions**
- **Scale up**
- **Economics**
- **Regulatory framework**
- **Long-term assurance and acceptance**



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RD&D Challenges

Pre-combustion
(Synthesis Gas)

- Loss of CO_2 pressure due to flash regeneration
- Cooling / refrigeration of syngas to accommodate low operating temperatures; reheating prior to combustion
- H_2 losses, particularly in membranes
- Sulfur-tolerant materials / membranes

Post-combustion
(Flue Gas)

- Low-pressure flue gas dilute in CO_2
- Steam requirement for thermal regeneration (amines)
- High compression costs and large loads due to CO_2 produced at low pressure
- Flue gas contaminants

Oxygen Combustion
(OxyFuel)

- Cost of O_2 production and materials
- Cooled CO_2 recycled to mitigate combustion temperatures

RD&D Challenges (cont'd.)

Laboratory

Technically possible?

Scale-up

Economically feasible?

500 MW Commercial Power Plant

- 0.1 ft^3 Reactor Volume
- 0.27 scf per minute

- 57,000 ft^3 Reactor Volume
- 1,800,000 scf per minute

Cost of Coal Technologies
Bituminous Coal

	Total Plant Cost $ / kWe		COE ¢ / kWh		Efficiency %HHV	
CO_2 Capture	NO	YES	NO	YES	NO	YES
Subcritical PC	1,550	2,900	6.4	11.4	36.8	25.0
Supercritical PC	1,570	2,850	6.3	11.1	39.1	27.2
Ultra-supercritical PC	1,650	2,850	6.4	10.6	44.6	32.0
IGCC[1]	1,850	2,500	7.8	10.2	39.5	32.0

[1]*Average IGCC (GE Energy, ConocoPhillips, Shell Global)*

Basis:
Econamine FG+ for PC CO_2 capture
Selexol™ for IGCC CO_2 capture
90% CO_2 capture
December 2006 dollars
Total plant cost includes contingencies

CO_2 Transport, Storage, and Monitoring:
To transport 50 miles, store in saline formation at 4,000 ft., and monitor for 80 years will cost additional ~0.4 ¢/kWh (~4 mills / kWh)

1. *2007 Pulverized Coal Oxyfuel Combustion Power Plants, U.S. Department of Energy National Energy Technology Laboratory, Draft Final Report, April 2007*
2. *Cost and Performance Comparison Baseline for Fossil Energy Power Plants, U.S. Department of Energy—National Energy Technology Laboratory, Draft Final Report, May 2007*

Cost of Coal Technologies

PRB Coal at Elevation

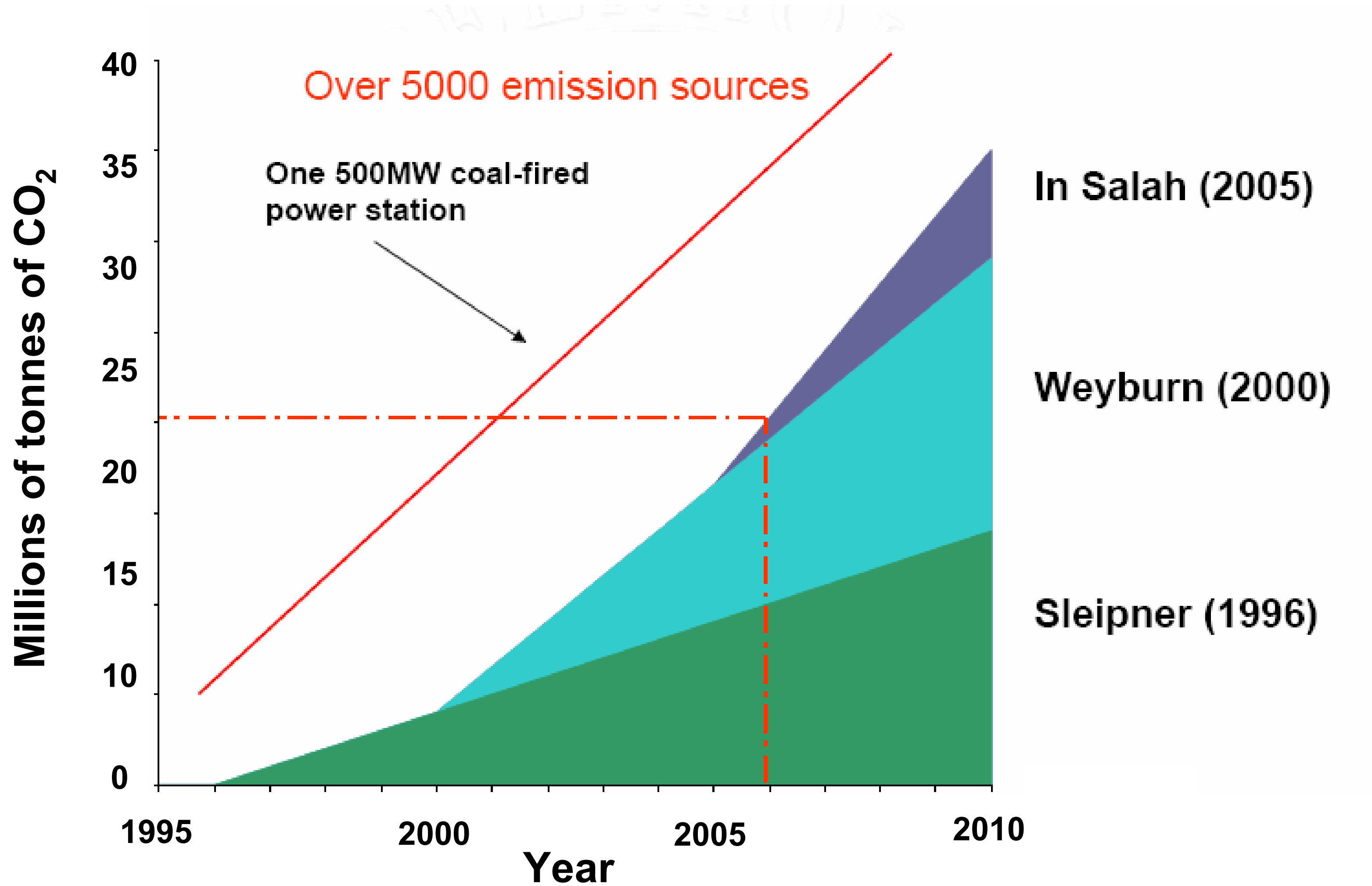
	Total Plant Cost $ / kWe		COE ¢ / kWh		Efficiency %HHV	
CO_2 Capture	NO	YES	NO	YES	NO	YES
Subcritical PC Supercritical PC Ultra-supercritical PC	↑ 50	↑ 150	↑ 0.5	↑ 0.8	↓ 1–2	↓ 2–2.5
IGCC[1]	↑ 100–200	↑ 300–500	↑ 1.5	↑ 2–2.5	↓ 2–2.5	↓ 2.5–3

[1] *Average IGCC (GE Energy, ConocoPhillips, Shell Global)*

Basis:
Wyoming PRB (8,340 Btu/lb)
Elevation 4,000 feet
90% CO_2 Capture

Estimated using the Integrated Environmental Control Model—Carbon Sequestration Version 5.2

Significant Quantity but Equal to One Large Coal-Fired Power Plant



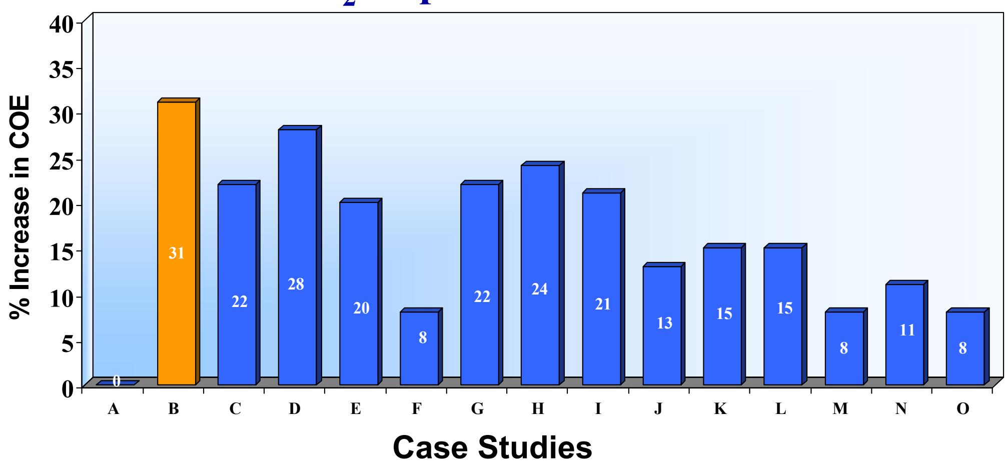
John Gale, IEA Greenhouse Gas R&D Programme

Permitting and Regulatory Issues

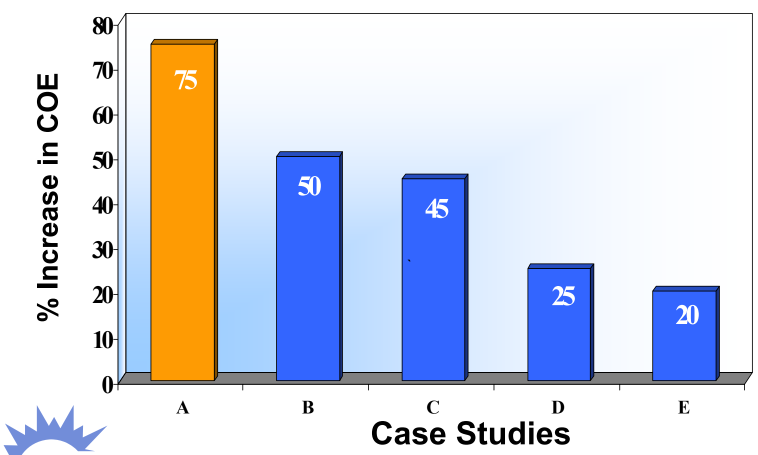
- Process undergoing definition
- DOE and EPA working together on technical issues
- EPA guidance for CCS RD&D projects
- Oil and gas recovery and CCS operations
- Saline CO_2 injection wells
- Interstate Oil and Gas Compact Commission
- Laying the groundwork for commercial projects
- Liability, legal, and public acceptance

NETL Analyses Determining Future Needs

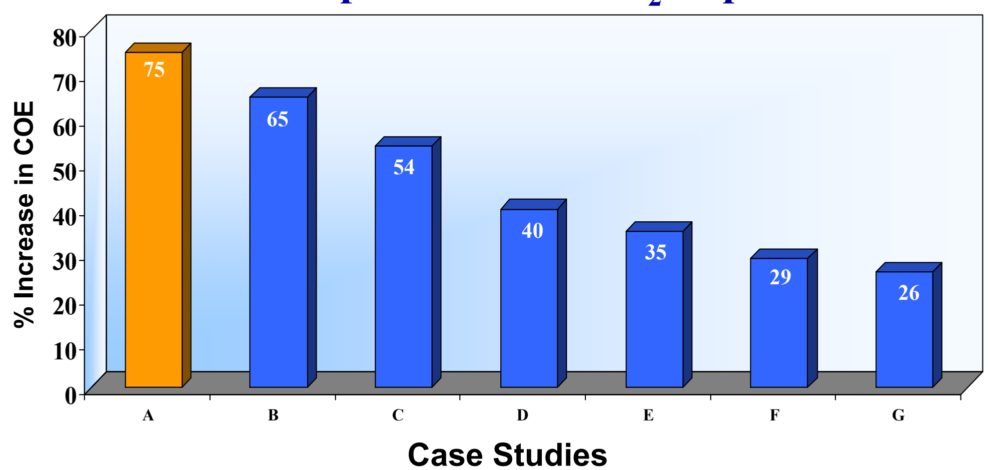
CO_2 Capture Economics for IGCC



Driving Down Oxyfuel Combustion Costs

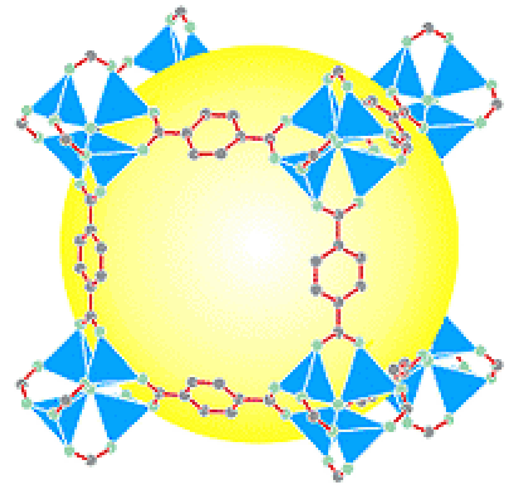


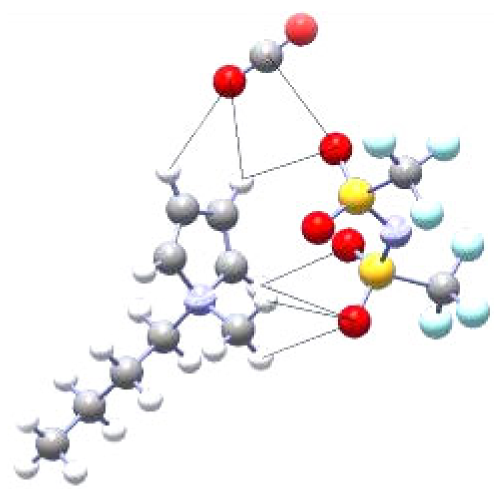
More Options for PC CO_2 Capture



Capture Innovations

- Ionic liquids
- Molecular organic frameworks (MOF)
- Ceramic Autothermal Recovery (CAR)
- Polymer-based high-temperature membrane
- Carbonic anhydrase enzymatic membrane
- Ammonia-based scrubbing
- Amine-enriched absorbents

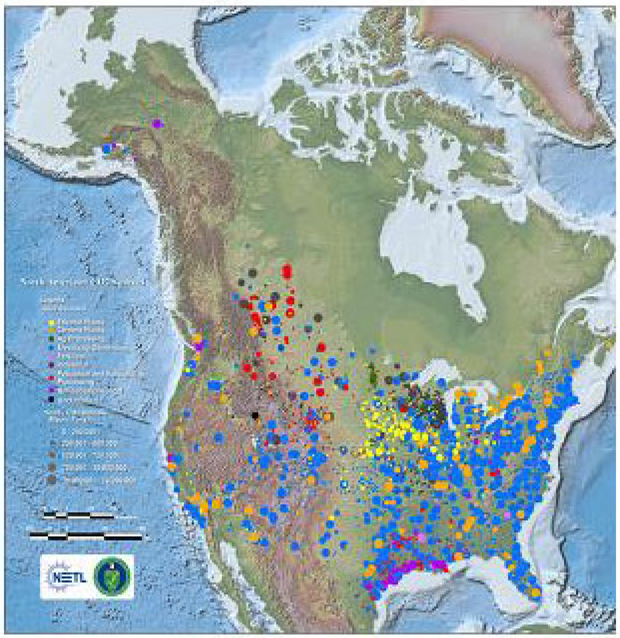




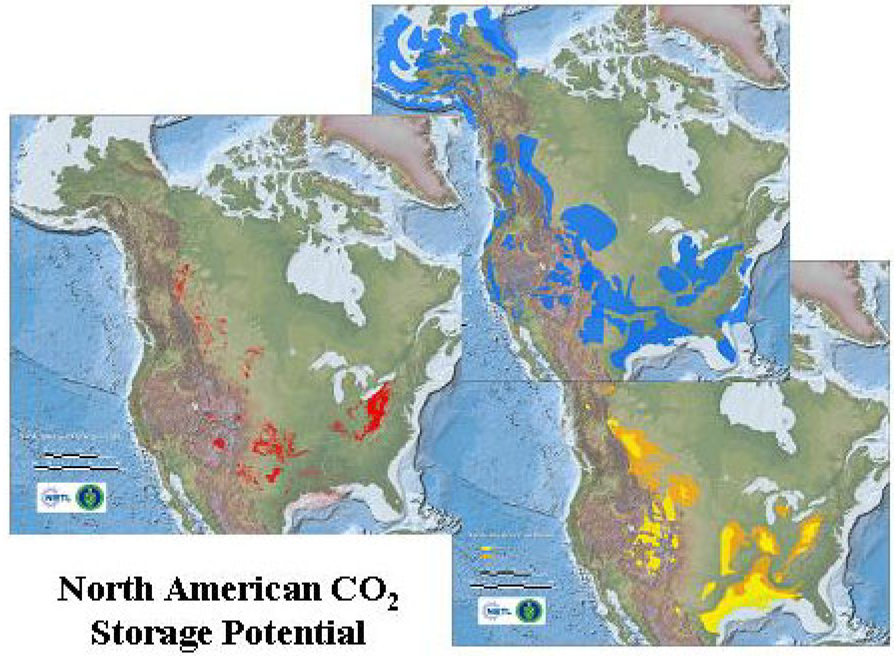
Adequate Storage Projected, National Atlas Highlights

CO_2 Sources Documented in NatCarb

	CO_2 Emission (Million Tons)	Number of Facilities
CO_2 Sources	3,809	4365



U.S. ~ 6 GT CO_2 / yr all sources

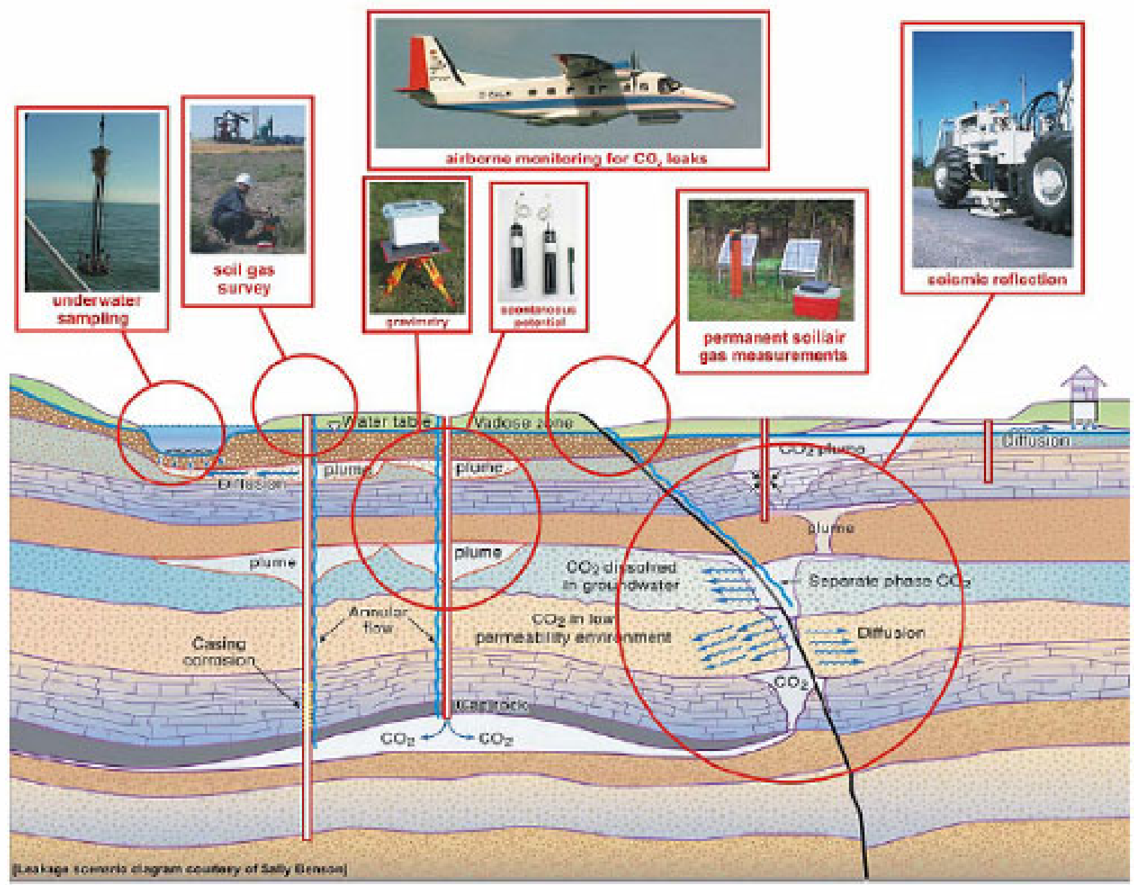


North American CO_2 Storage Potential (Gigatonnes)

Sink Type	Low	High
Saline	919	3,378
Unmineable Coal Seams	156	184
Oil and Gas Fields	82	91

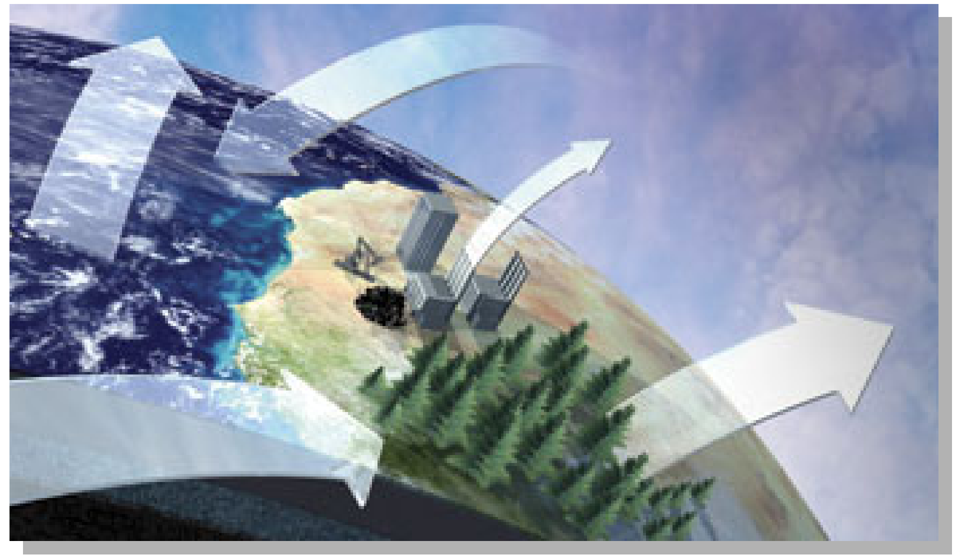
Monitoring, Mitigation, and Verification

- Proper site characterization is critical to understand
- Transport modeling and MMV
- Wellbore integrity



Conclusions

- Need for carbon capture and storage substantial, but so are opportunities
- Challenges exist
- Research and large-scale evaluation are required
- Safe commercial implementation highly probable



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